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# Advanced Launch System (ALS): Electrical Actuation and Power Systems Improve Operability and Cost Picture

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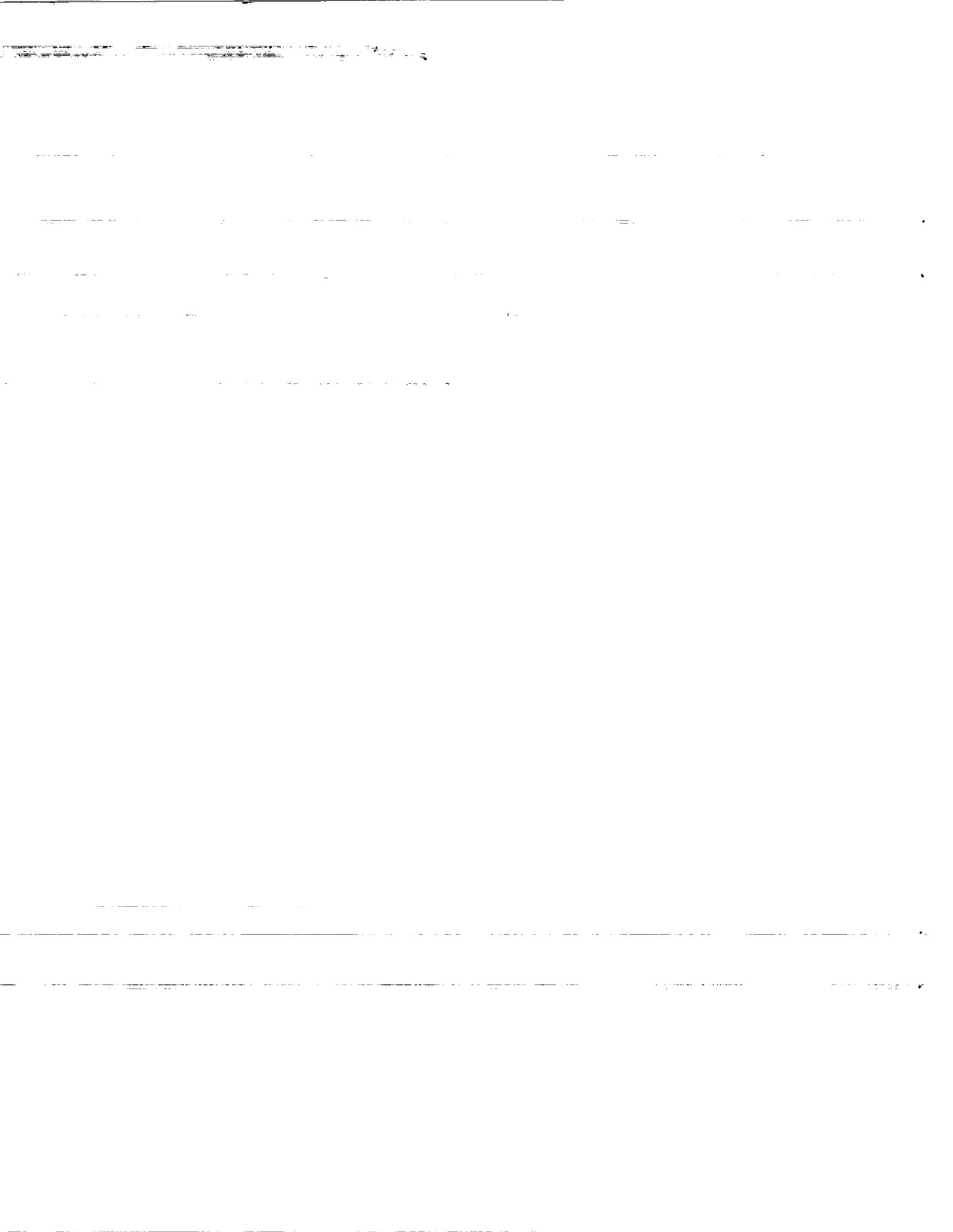
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# ADVANCED LAUNCH SYSTEM (ALS): ELECTRICAL ACTUATION AND POWER SYSTEMS

## IMPROVE OPERABILITY AND COST PICTURE

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### Abstract

To obtain the Advanced Launch System (ALS) primary goals of reduced costs (\$300/lb earth to LEO) and improved operability, there must be significant reductions in the launch operations and servicing requirements relative to current vehicle designs and practices. One of the primary methods for achieving these goals is by using electrical actuation integrated with a single vehicle electrical power system and controls for all actuation and avionics requirements.

This paper will give a brief status review of the ALS and its associated Advanced Development Program to demonstrate maturation of those technologies that will help meet the overall operability and cost goals. The electric power and actuation systems will be highlighted as a specific technology ready not only to meet the stringent ALS goals (cryogenic fuel valves and thrust vector controls with peak power demands to 75 hp), but also those of other launch vehicles, military and civilian aircraft, lunar/Martian vehicles and a multitude of commercial applications.

### Introduction

To obtain the Advanced Launch System (ALS) primary goals of reduced costs (\$300/lb earth to LEO) and improved operability, there must be significant reductions in the launch operations and servicing requirements relative to current vehicle designs and practices. One of the primary methods for achieving these goals is by using electrical actuation integrated with a single vehicle electrical power system and controls for all actuation and avionics requirements.

Electrical actuation will eliminate a major and persistent problem with liquid engine valves, hydraulics and plumbing causing propulsion failures and delays such that launch reliability has plateaued in the 0.92 to 0.96 range. It will also significantly reduce the energy, peak power requirements and weight, while raising system efficiencies from 2 percent to well over 80 percent when compared to centralized hydraulics.

The greatest benefits, however, accrue due to savings in prelaunch testing time permitted by the elimination of hydraulics and plumbing, and the substitution of electrical actuation and an integrated electrical power system. The magnitude of these savings could exceed 10 percent of the total vehicle operations costs according to a study by the General Dynamics Corporation showing a 5400 man-hour savings for their Atlas/Centaur (A/C) launch vehicle and a 16 000 manhour savings for the Space Shuttle based on a Boeing Aerospace study of operations at Cape Kennedy. Figure 1 illustrates these potential cost savings for electrical actuation systems.

In the case of the Space Shuttle a preliminary Assured Shuttle Availability study has shown a reduced turn-around time at KSC using electric actuators, such that at least one additional Shuttle flight per year may be possible. In addition, a weight savings of 2300 kg could either increase the payload or engine margins.

Recent advances in power control and distribution systems and newly demonstrated capabilities for high torque/speed control of a larger class of inherently rugged, induction motors using pulse-population-modulation with field-oriented control from a high frequency resonant link make the all electric approach even more attractive. For example, selective steering of high frequency, small energy pulses and switching at zero crossing significantly reduces the size and weight of the electronics while practically eliminating EMI/EMC effects. In addition, using embedded microprocessors and smart components with microchip BITE for remote identification/self-checking will enable distributed system intelligence and fault tolerance in both of the power and the avionics systems without massive software investments.

This paper will give a brief status review of the ALS program and its associated Advanced Development Program to demonstrate maturation of those technologies that will help meet the overall operability and cost goals. Figure 2 shows the primary subsystems that make up a typical electromechanical actuator for thrust vector control of a launch vehicle. The electric power and actuation systems will be highlighted as a specific technology ready not only to meet the stringent ALS goals (cryogenic fuel valves and thrust vector controls with peak power demands to 75 hp), but also those of other launch vehicles, particularly evolutionary Space Shuttle, Assured Crew Return Vehicle, military and civilian aircraft, lunar/Martian vehicles and a multitude of commercial applications.

### Major Objectives

The scope of the ALS Advanced Development Program tasks is to develop, demonstrate and transfer (to vehicle/equipment manufacturers) the technology for electromechanical actuators (EMA) and/or contained electro-hydraulic actuators (EHA) integrated with a single vehicle electrical power system and controls. Both EMAs and EHAs are electrically driven by motors and will be referred to as electric actuators.

Reduce KSC Turn-Around Costs and Standdown Time:  
Increase Launch Rate: Decrease Weight

For any launch system the key objective is to reduce the turn-around time and costs at KSC and, thereby, increase the launch rate, improve the dispatch reliability and enable launches even from a last second hold. Use of electric actuators will

eliminate excessive manpower intensive testing and qualification procedures. Eliminating centralized hydraulics will eliminate ground support carts and associated equipment and the problems of fluid contamination and hydraulic silting. At the present time a study team at KSC composed of Flight Controls personnel and Lockheed are reviewing NSTS logbooks to assess turn-around flow and subsystem processing costs due to the hydraulic systems. They are establishing an analysis network of critical paths to provide quantitative trades of several items that impact Shuttle operations and the number of launches per year.

#### Improve Redundance, Reliability, Dispatch Reliability, and Safety

Electric actuation is a demand driven system providing high peak power and torque, but it uses small amounts of total energy. Therefore, APUs and their associated hazardous fuels may be eliminated and replaced by batteries, fuel cells or an electric APU. In addition electric actuators require low amounts of standby power and energy. Electric motor driven actuators are easy to implement and to integrate automated, remote, self check-out through microchip built-in-test (BITE). Smart BITE microchips designed in, built-in at manufacture and easily monitored by technicians and controllers provide a path to vehicle health monitoring with a minimum of software.

#### Significant Research Activities

There are six candidate Government supported programs that are working on relevant technologies or could have significant applications for electric actuators and an integrated power distribution and control system. The programs are listed below with a brief explanation and noteworthy technology.

#### Advanced Launch System

Four Advanced Development Tasks are directed to the development and demonstration of electrical actuators and electrical power systems for the proposed new family of heavy lift launch vehicles. Actuators for thrust vector control (TVC), fuel valves and others with ratings in the ranges of 5, 25, 40, and 75 hp are being developed and subsystem demonstrations before March 1992. Figure 3 shows the ALS EMA system demonstration activities and milestones. Inspection of Table I shows that these actuator values fit easily within the actuation requirements for all launch vehicles commonly used by the United States today including the Space Shuttle.

The primary development work on three of the tasks is being done by two of the ALS vehicle prime contractors - General Dynamics Space Systems and Boeing Aerospace Company - and one of the engine contractors - Aerojet General. The fourth task is being conducted by Lewis to provide advanced motor drive technology, motor designs, BITE concepts and vehicle/actuator requirements and transfer the technologies directly to all the primes. The 5 hp drive has been demonstrated, the 25 hp drive and actuator will be tested in March 1990, and the 30 and 40 hp actuators will be ready by early 1991.

The power semiconductors necessary to meet the peak horsepower ratings are now available and improved MOSFET Controlled Thyristors (MCT) will be available in 6 months. Circuit topologies and system architectures are available, which meet required redundancy, fault tolerance and fault containment.

An appropriate power control and distribution system integrated with an avionic and propulsion system will demonstrated in 1992.

#### Space Shuttle Evolution/Shuttle "C"

JSC has supported several electric actuation and power source studies over several years. A preliminary Assured Shuttle Availability study by Rockwell Downey concluded that electric actuation was feasible, the technology was ready and a 5 to 6 year schedule was reasonable to accomplish the DDT&E required to retrofit electric actuators into the existing Shuttle Orbiters. JSC is also supporting an analysis of 10 Shuttle subsystem processing costs and turn-around flows. The EMA system is planned as the vanguard item to trade against the existing hydraulic systems. Shuttle "C" is a cargo version of the Space Shuttle, which will benefit significantly by application of electrical actuation systems.

#### Civil Transport: Power-by-Wire/Fly-by-Light

This program is a planned new initiative for FY91/92. The power-by-wire (PBW) portion of the program includes an all electric secondary electrical power system that includes electrical actuators, embedded engine generators, fixed bleed turbine engines, advanced power distribution architectures, BITE and electric driven environmental control systems. Studies at Lewis on a Boeing 767 class aircraft have shown a potential weight and fuel savings of nearly 10 percent by using the PBW approach. Plans in this initiative include development, fabrication, testing and flight evaluation of engineering prototypes by 1996.

#### Lunar/Mars Initiative

Preliminary assessments have been made by the agency for a report to the Space Council. Several scenarios, however, require relatively high power distribution systems and include surface rovers and mining vehicles that will require reliable, power efficient actuation and variable speed motor drive systems.

#### AF/WRDC - More Electric Airplane - Retrofit of F-16

Wright Research and Development Center under their More Electric Airplane Program has contracted General Dynamics of Fort Worth, TX to do a trade study of the F-16 resulting in development costs, risks, and payoffs expected by replacing hydraulics with electrical actuation systems. Performance, operability, maintainability and recurring cost reductions are the main drivers.

#### David Taylor Ship R&D Center - Electric Navy

The US Navy has begun a massive joint program with DARPA to develop technologies that will enable all electric variable speed drives of both the main propulsion engines and new weapon systems. This will require megawatts of power generation and distribution capability with new types of electronic control and motor drives. They plan to demonstrate a 200 hp drive by the end of 1991 and work toward a capability to drive 3600 hp induction motors. Motor drives and the required very high power MCTs and associated electronic components are already under intensive development and planned qualification. New programs include development of electric actuators to replace many hydraulic actuation systems.

Commercial Technology Transfer

Several applications are being explored through the NASA Lewis Research Center Technology Utilization Office to apply the advanced electrical distribution system and actuation systems within the commercial sector. The capability to drive induction motors at variable speed with independent control of torque, speed and direction opens up a vast opportunity. Nearly 70 percent of all electrical power consumed in the US drives induction motors. The capability to control these motors more efficiently and in servo applications could revolutionize many industrial motor applications. In addition many companies are investigating innovative electrical applications to automobiles, other vehicles, appliances and many other products.

Summary

Electrical actuation, advanced electrical power and avionics systems are ready today for flight validations. Figure 4 is a summary of the

General Dynamics Space Systems assessment of technology readiness of electric actuation for ALS and the National Space Transportation System (NSTS). System requirements, specific DDT&E and resources, however, are needed to bring the technology to maturity in a particular system application.

Adoption of Total Quality Management (TQM) practices on other systems besides ALS could cause a revolution in achieving reduced operations costs and improved operability of systems such as the NSTS. To incorporate TQM, however, will require some significant cultural changes that bring several NASA organizational codes to work together in such a manner that candidate technologies from the R&D sectors can be focussed and brought to maturity in the appropriate environment. In this regard NASA is planning a technology bridging program in which one of the pilot initiatives will be to mature electrical actuators/power systems for advanced space vehicle applications.

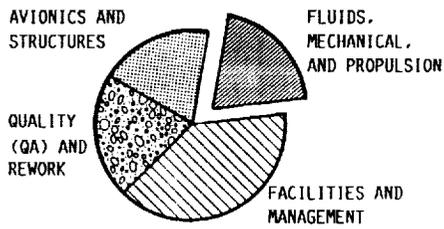
TABLE I. - ALS FAMILY OF ELECTRIC ACTUATORS MEET STS NEEDS

	Engine prevalve	Titan III stage 1 <sup>a</sup>	Atlas booster	EMA 25 hp	Titan IV SRM upgrade <sup>a</sup>	STS flt cont.	SRB	ALS prel.	STS
Stall load, lb	(b)	29 790	10 750	29 630	73 940	--	96 840	90 750	74 400
Dynamic load, lb (at actuation rate)	(b)	11 330	7 510	19 700	28 692	--	-----	60 380	48 000
Actuation rate, deg/sec	(b)	10	9	15	10	--	10	15	20
Fluid pressure, psig	300	(b)	(b)	(b)	(b)	--	(b)	(b)	(b)
Flow rate, lb/sec	1250	(b)	(b)	(b)	(b)	--	(b)	(b)	(b)
Response time, sec -close	1-2	(b)	(b)	(b)	(b)	--	(b)	(b)	(b)
Actuation power, hp	2.1	4.3	6	25	32	40	68	75	100

<sup>a</sup>"Applicable TVC for ALS and MOOG Position Statement," MOOG Inc., Missile System Division, East Aurora, New York 14052.

<sup>b</sup>Parameter not applicable.

LAUNCH OPERATIONS COSTS

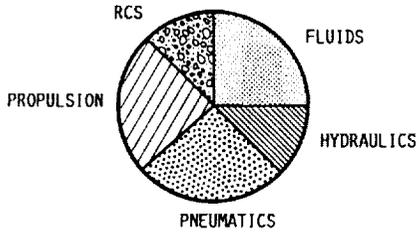


TOTAL A/C LAUNCH OPERATIONS 91 575 HRS

TOTAL IF/MP TEST TIME	19 197 HRS	% SAVINGS IF EMAs USED	SAVINGS
FLUIDS	4929 HR	10%	490
HYDRAULICS	2177 HR	90%	1960
PNEUMATICS	5143 HR	40%	2060
PROPULSION	4616 HR	20%	920
RCS	2333 HR	> 8%	0

5430 HR

FLUIDS, MECHANICAL AND PROPULSION TEST COSTS



TOTAL STS LAUNCH OPS 326 444 HR  
EQUIVALENT SHUTTLE HOURS

PLUMBING, VENT, AND DRAIN	2880 HR	20%	576
HYDRAULICS	4236 HR	90%	3812
PROPULSION	27 200 HR	10%	2720
ACS	5654 HR	> 8%	0

VAB ACTIVITIES  
PAD OPERATIONS (35%)  
5670  
3600

16 378 HR

USE OF ELECTROMECHANICAL VALVES AND ACTUATORS CAN REDUCE A/C TEST TIME BY >5000 HR, AND POTENTIALLY >16 000 HR FOR THE SHUTTLE

FIGURE 1. - POTENTIAL SAVINGS FROM ELECTRIC ACTUATORS.

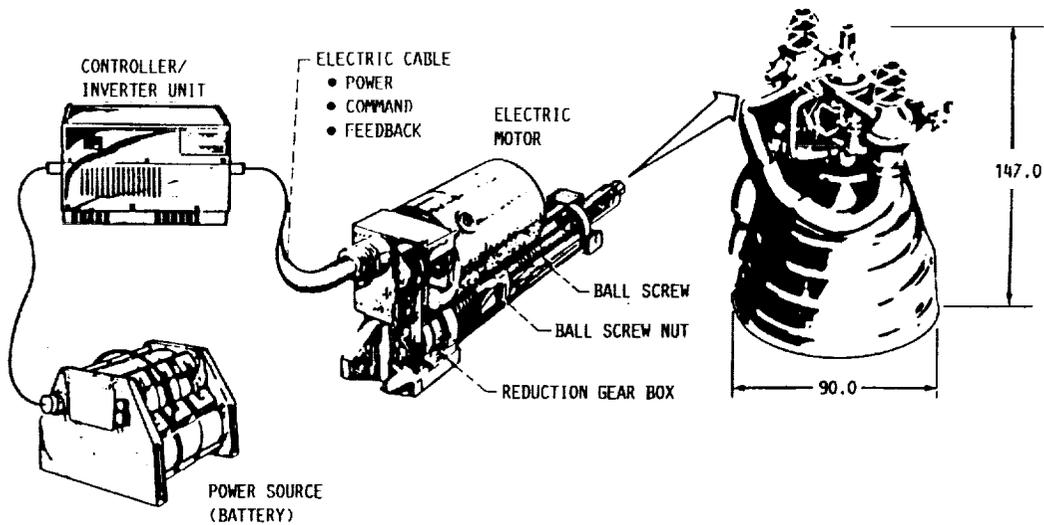


FIGURE 2. - TYPICAL MAJOR EMA SUBSYSTEMS.

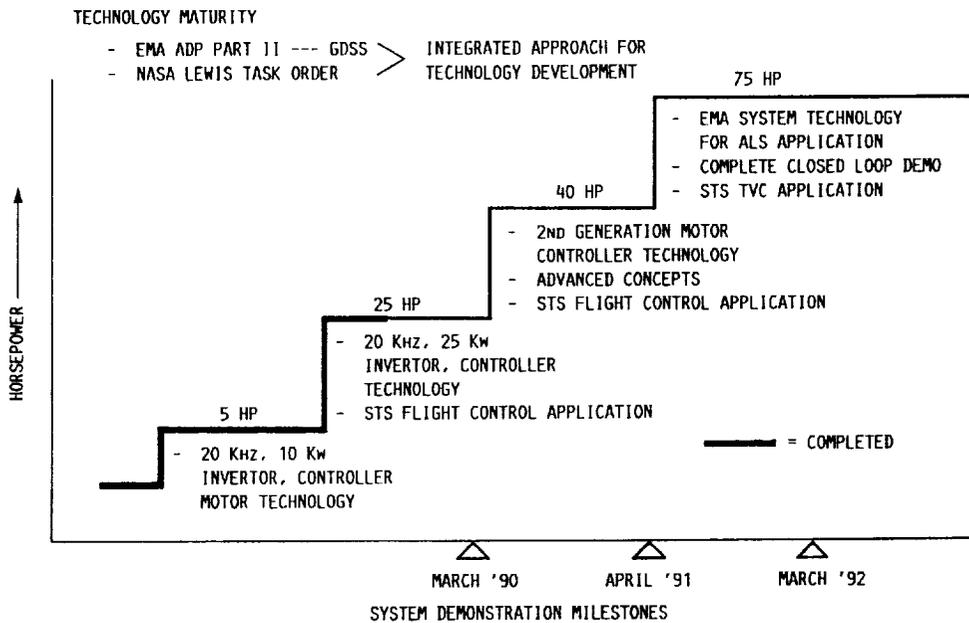


FIGURE 3. - ALS TOTAL SYSTEM APPROACH FOR ELECTRIC ACTUATORS.

#### SUMMARY

- PRELIMINARY EMA TRADES ARE COMPLETE
  - ALS REFERENCE VEHICLE
  - SHUTTLE ORBITER CLASS VEHICLES
- HARDWARE DESIGNS ARE NOW IN WORK
  - ORDERLY PROGRESSION TO FULL POWER
- ALL THE BASIC REQUIRED TECHNOLOGIES ARE AVAILABLE
  - POWER PROCESSING TECHNOLOGY AND COMPONENTS
  - AC MOTORS
  - COMPUTER CONTROLS AND MOTOR CONTROL ALGORITHMS
  - MECHANICAL COMPONENTS

FIGURE 4. - GENERAL DYNAMICS ASSESSMENT OF TECHNOLOGY READINESS FOR ELECTRIC ACTUATORS.



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